Abrupt Climate Change and the Economy:
A survey with application to Oregon

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Sponsorship

This report was sponsored by the Climate Leadership Initiative (CLI) at the University of Oregon. The CLI is an educational, research, and technical assistance consortium aimed at increasing public understanding of the risks and opportunities posed by global warming. Website: http://climlead.uoregon.edu

1. Introduction

The general warming of the Earth that is expected over the next century will have serious economic consequences for humans and natural ecosystems across the world. The Pacific Northwest is already experiencing adverse affects and more are likely the warmer it gets. [Resource Innovations (2005)] This will be true even if warming proceeds gradually. Globally, temperatures are expected to rise between 1° and 5° c (2°-10° F) over the next hundred years. [IPCC (2001)] Regional warming is expected to be 5.4 ° F by mid-century. [Institute of Natural Resources (2004)] To put these numbers in perspective, during the last Ice Age, global temperatures averaged 9° F cooler than today, so a mid-range warming will approach a swing in global temperatures of Ice Age magnitude, only in the opposite direction. In Oregon, the most visible short run impacts will be felt through loss of snowpack and dramatic reductions in summer water supply for agriculture, and municipal and in-stream uses, as well as through sea level rise, and forest impacts. [Resource Innovations (2005)] This paper sketches the possibilities for more abrupt changes in the climate system, which would have potentially catastrophic impacts for the Oregon's economy, and evaluates insurance motives for reducing global warming emissions in the state.

There are four major categories of abrupt climate change currently under consideration by the scientific community that could be triggered as the planet warms. Each of these possibilities results from feedback mechanisms, where changes in one climatic variable such as temperature triggers changes in other variables, creating a self-amplifying affect. Thus, seemingly small changes in temperatures can have unpredictable large-scale reinforcing effects. First, a "collapse" of the West Antarctic or Greenland Ice Sheets would lead to an irreversible, massive sea level rise: up to 48 feet over the course of a few hundred years. Second, acidification of the oceans could severely impact ocean food chains, leading to large scale reductions in fish harvests. Third, a complete or partial shutdown of the ocean's thermohaline circulation system could lead to very sudden regional climate shifts; rapid cooling in the North Atlantic, coupled with more rapid warming in equatorial regions, all with unknown consequences for the Pacific Northwest. Finally, a gradual warming could trigger release of methane trapped in permafrost and along the continental shelf of the ocean floor. Methane is a very powerful heat trapping gas, so any large-scale methane release could lead to very rapid warming of the planet. Some scientists believe that a similar event contributed to the mass extinction at the end of the Permian era 250 million years ago, which wiped out between 70% and 90% of life on the planet. [Kennet et al (2002)]

None of these events will occur with certainty; each is only a possibility, with an unknown probability. When faced with the possibility of large but uncertain future losses—as with fire or health risks--economic actors typically take steps to insure against potential negative outcomes. The possibility of catastrophic climate change thus provides an insurance rationale for steps to reduce the emission of heat-trapping global warming gasses. The amount of mitigation undertaken as insurance will depend on (1) the magnitude of the possible damage, (2) the probability of the adverse outcome, and (3) the efficacy of mitigation in reducing risk. This paper explores the possible damage to the

Oregon economy from one—and perhaps the most likely-- catastrophic outcome of climate change: large scale sea level rise from the collapse of one or both major continental ice sheets. We then turn to a discussion of mitigation as an insurance strategy.

2. Abrupt Climate Change Scenarios

2.1. Continental Ice Sheet Collapse.
Much of the world's fresh water is locked up in the massive ice sheets on Greenland and Antarctica. Sea level can rise rapidly when the melting of ice sheets is lubricated by meltwater, creating a "collapse". If the Greenland and West Antarctic Ice Sheet were to melt completely, sea level would rise by about 48 feet, flooding most of the world's coastal cities, inundating Oregon's coastal communities, turning the Willamette River at Portland into a salt water estuary, and bringing the shoreline of the Pacific Ocean well into Portland's' downtown.

Sea level rise of dozens of feet, if a collapse did occur, would likely not be completed for several hundred years. However, once a temperature threshold that initiates a collapse was crossed, catastrophic sea level rise would be extremely difficult to prevent. Moreover, on a much shorter timeframe of decades, ice sheet collapse would inundate the state's coastal regions, while also flooding large portions of low lying regions like Florida, Bangladesh, the Nile Delta, and many island nations, leading to the forced migration of hundreds of millions of people.

Coming out of the Ice Age 14,000 years ago, sea level rose by about 3 feet every twenty years. And during the peak of the last interglacial warm period, about 100,000 years ago, the planetary temperature was about 2° F warmer than today, and sea level was 20 feet higher. However, collapse of the continental ice sheets are by no means certain: warming may lead to increased snowfall which could help offset ice-sheet melting, and hold sea level rise at a minimum. [Hansen (2005)] What we know is that sea level can rise by fifteen feet per century, and that in a slightly warmer world, sea level has been substantially higher than it is today. The risk of ice sheet collapse is thus very real, though with highly uncertain probability. Although the most extreme consequences would not be felt for over a hundred years, decisions we make today regarding the emissions of heat-trapping gasses will either increase or decrease the likelihood of a collapse.

Scientists are not in agreement about the likelihood of a continental ice-collapse. Hansen (2005) argues that a very small warming- on the order of 1° c (2° F) -- could trigger such a phenomenon. Oppenheimer and O'Neil (2002) feel that a margin of safety is available up to 2° c (4° F). In contrast, the Intergovernmental Panel on Climate Change (2001) argued an ice sheet collapse was unlikely to occur in this century. In early February of 2005, however, Professor Chris Rapley, director of the British Antarctic Survey (BAS) reported on recent findings of rapid ice discharge from Antarctica: "The last IPCC report characterized Antarctica as a slumbering giant in terms of climate change. I would say it is now an awakened giant. There is real concern. The previous view was that WAIS would not collapse before the year 2100. We now have to revise that judgment. We cannot be so sanguine." [McCarthy (2005a)]

Rapley's concerns were reinforced by data from Satellite imagery released in February 2006, which found that Greenland's ice sheets are melting twice as fast as previously believed. Researchers found that in 1996 the amount of water produced by melting ice in Greenland was about 90 times the amount consumed by Los Angeles in a year. In 2005 the ice melt amounted to 225 times the volume of water that Los Angeles consumes each year. Eric Rignot, from the California Institute of Technology's Jet Propulsion Lab and an author of the report said: "We are witnessing enormous changes, and it will take some time before we understand how it happened, although it is clearly the result of warming around the glaciers." [Rignot and Kanagaratnam (2006)]

2.2 Ocean Acidification.

Over the past hundred years, the world's oceans have absorbed about half of the carbon dioxide emitted from the burning of fossil fuels. This has already begun to alter ocean chemistry, making sea water noticeably more acidic— with a potential drop of .5 units on the pH scale by 2100. Organisms most likely to be severely affected are those which make calcium carbonate shells, often supporting the bottom of the food chain: corals, crustaceans, mollusks and certain types of plankton. Further ocean acidification is a virtually certain outcome of the emission of carbon dioxide from fossil fuels. The economic impacts remain uncertain given our limited understanding of ocean ecosystems. However, one very real possibility would be large-scale reductions in ocean productivity.

Dr Carol Turley, the head of Britain's Plymouth Marine Laboratory recently said ocean acidification represented "potentially a gigantic problem for the world. It's urgent indeed to warn people what's happening. Many of the marine species we rely on to eat could well disappear. In cartoon terms, you could say people should prepare to change their tastes, and switch from cod and chips, to jellyfish and chips." [McCarthy (2005b)]

2. 3. Ocean Thermohaline Shutdown

One of the early concerns about abrupt climate change revolved around the potential for a shutdown of the Earth's marine thermohaline circulation system. The ocean circulation system acts as a vast heat pump, redistributing warmth from equatorial regions to northern climates. The best known surface manifestation of this vast planetary conveyor belt is the Gulf Stream, whose current brings vast amounts of heat north and keeps high latitude northern Europe unusually temperate, before the dense, salty waters sink off the coast of Norway and flows south at the bottom of the ocean. However, when the North Atlantic is flooded with fresh water, the Gulf Stream becomes less dense, and can grind, rather quickly, to a halt. This happened around 12,000 years ago, when the Earth was coming out of the last Ice Age. When a giant ice-dam in northern Canada broke, flooding the North Atlantic with freshwater, the conveyor belt shut down, and temperatures in Europe plunged back to Ice Age conditions in the space of a decade—remaining there for about 1000 years.

The fear is that melting ice in the Northern hemisphere could have the same effect—although a new Ice Age appears unlikely, given the background of a rapidly warming world. If the Gulf Stream were to shut down, climate would change rapidly across much of the Northern Hemisphere. The implications on the Pacific Northwest and Oregon would be very hard to predict, but it could well lead to dramatic and unexpected regional climate variability on an annual scale. Although a conveyor belt shutdown has received a lot media attention, many climate scientists view a thermohaline shutdown as unlikely this century, assuming a mid-range warming. [Schiermier (2006)] Oppenheimer and O'Neil (2002), for example, argue that the conveyor belt will probably hold up against a 3° c (6° F) warming.

2 .4. Large Scale Methane Release

The final abrupt climate change scenario of concern would be the large-scale release of methane that is trapped either in permafrost or in the form of "ice-like" crystals called clathrates on the ocean's continental shelves, held in place by a combination of temperature and water pressure. Methane is a very potent global warming gas, and so a large scale methane release could contribute to very rapid increases in global temperature. Some scientists believe that this kind of rapid warming contributed to the Permian extinction 250 million years ago, in which 70% of terrestrial and 90% of marine life was driven into extinction. More recently, a debate has emerged as to whether the warming at the end of the last Ice Age was sufficient to trigger significant methane releases from clathrates. [Kennet et al (2002); Economist (2003)]

Archer (2006a) argues that the ocean floor clathrates appear unlikely to be major methane source this century; however, releases from previously frozen peat could potentially double methane concentrations in the atmosphere within 100 years: "not an obvious disaster-movie plot, but a potential positive feedback that could turn out to be the difference between success and failure in avoiding 'dangerous' anthropogenic climate change. That's scary enough." [Archer (2006b)]

This brief overview describes four potential catastrophic outcomes that could be triggered by the warming over the next century. The next section explores in detail the consequences of one abrupt climate change scenario: collapse of the continental ice sheets.

3. Impacts on Oregon of Ice Sheet Collapse

The Antarctic Ice Sheet is divided into two sides: east and west. Concern is focused around the potential collapse of the West Antarctic Ice Sheet (WAIS) because large portions of the bottom of this sheet actually touch land below sea level. Due to the lubricating action of seawater, this ice sheet has proven to be unstable throughout geologic time. The WAIS contains enough fresh water to raise sea level 8 M (26.4 ft). Turning to Greenland, a recent research summary concluded, "Complete or partial deglaciation…may be triggered for even quite modest stabilization targets." [Lowe et al (2006)] A complete collapse of the Greenland Ice sheet could raise sea level by an additional 6.5 M (21.5 ft). [USGS (2005) and Williams and Hall (1993)]. Figures 1 and 2 present a GIS analysis of the impact of first, the collapse of the WAIS, and then the Greenland Ice Sheets on sea level and the Oregon coastline.

Visual inspection of the figures suggests the dramatic impacts. Most coastal towns in Oregon would be completely inundated; the Tillamook valley, for example, disappears. With a 26 Foot rise, the coast of the Pacific Ocean rises to First Avenue in downtown Portland; a 47-foot rise puts the coastline on 14th. Table 1 provides the results of the GIS analysis of impacted areas and structures; total acreage inundated varies between 276,000 and 378,000 acres, with 10-15% of that total being urban land. Between 50,000 and 92,000 people currently live in these areas, and the economic impacts would also include damage to agricultural, commercial and industrial sites. Again, this kind of sea level rise, once initiated, would take place "gradually" – at a rate of 5-10 feet per century over the space of several hundred years. People would as a result face, not immediate, but escalating flooding threats. And while some dikes could be built to protect very high value real estate, much of the impact would be unavoidable.

Feature	WAIS 26.4 foot rise	WAIS + Greenland 47.9 foot rise
Total affected area (acres)	276,815	378,537
Urban areas (acres)	27,935	41,203
Affected population	50,255	92,880
Miles of Highway 101	70.39	122.33
Miles of major roads	310.26	570.72
Miles of minor roads	1,328.96	2,173.30
Miles of utility lines	44.11	70.89
Miles of railway	276.62	522.49

Table 1: Impacts of Ice Sheet Collapse on Oregon

4. Mitigation as Insurance

When faced with the possibility of large future losses occurring with some (roughly) known probability, individuals typically choose to purchase insurance to reduce risk. Three problems emerge when assessing the right "premium" for insuring against global warming. First, what are the expected damages? Section 3 above sketched out in a very preliminary fashion the magnitude of damage that would be expected from continental ice sheet collapse. Second, what is the probability of a catastrophic outcome? This issue is discussed below. Third, how effective is the insurance premium in reducing risk? We turn to this issue in the final section.

Based on a survey of experts, Nordhaus and Boyer derive subjective estimates of the probability of a catastrophic climate change (a long term reduction in GDP of 22%, roughly equivalent to the US experience during the Great Depression) to be 1.2% for a 2.5° c (5° F) warming, and 6.8% for a 6° c (12° F) warming. Note these are not estimates for any particular catastrophic outcome, just guesses by experts about the probability that some combination of catastrophic outcomes will lead to large reductions in economic well-being. Utilizing these estimates, and assuming that individuals are risk averse, Nordhaus and Boyer use conventional insurance rules of thumb to suggest that American's would be willing to pay .45% of GDP to avoid the risk associated with the lower end warming, and 2.53% of GDP to avoid the risk associated with the higher end warming. For the nation as a whole, the estimated insurance premium for eliminating risk would thus be between about $45 and $250 billion.

Oregon is more vulnerable than most of the United States to a high end global warming due to our dependence on mountain snow pack for summer water storage, and also to potential catastrophic climate change arising from sea level rise and ocean acidification due to our extensive coastline. Applying Nordhaus and Boyer's estimates to Oregon's 2004 Gross State Product of $128 billion would suggest a willingness to pay for insurance to avoid catastrophic outcomes by the public of between $570 million and $3.24 billion dollars.

5. Does Mitigation Buy Risk Reduction?

Would Oregon expenditures to reduce greenhouse gas emissions actually reduce the risk of a high-end warming or catastrophic climate change? Oppenheimer and O'Neil (2002) suggest a stabilization target for carbon dioxide concentrations in the atmosphere of 450 ppm, in order to hold warming to 2° c (4° F), and provide a margin of safety against ice sheet collapse. To achieve this goal will require global reductions in emissions of carbon dioxide on the order of 80% by 2100. (Goodstein (2004: Chapter 1)) This in turn will require a radical transformation of the global energy industry, away from fossil fuels to energy sources that are low or carbon free. Such a transformation is not without precedent: just over 100 years ago, the global transportation network was still largely dependent on animal power. However, without policy leadership, such a rapid technological shift is unlikely to occur.

Due to their modest and often experimental nature, early efforts to reduce greenhouse gas emissions—by states or nations-- will obviously have little measurable impact on carbon dioxide concentrations or future global temperatures. Instead policy steps taken today should be evaluated in terms of their ability to clearly signal to market actors of the need for fundamental changes in energy production and consumption. Oregon's leadership in 1997—requiring new power plants to reduce or offset greenhouse gas emissions—had that effect, setting in motion adoption by other states of similar statutes. Similarly, assuming Oregon adoption California's Clean Car standards, the direct effect of cleaner cars in Oregon on future global temperatures will be small. But, action in Oregon will trigger the State of Washington's adoption of similar standards. The cumulative impact of close to half of the North American auto market becoming a clean car market by 2009 will have profound impacts for the future development of vehicle technology.

Along with the Clean Car proposal, Oregonians are considering two other major policy initiatives designed to reduce global warming pollution: a carbon cap-and-trade system and a renewable portfolio standard proposal, both for electricity sellers. In each of these cases, incremental costs for Oregon consumers are likely to range from relatively small to negative (the policies will save money). In the Clean Car case, consumers may well benefit on net from greater fuel efficiency. Washington State estimates that Washingtonians will save $2 billion by 2020 as a result of the Clean Car regulations.[1]

The costs of carbon cap-and-trade in New England (the Regional Green House Gas Initiative) are estimated to increase retail electricity prices between .33 and 1.1 percent by 2021. On net, if auction revenues from the program are used to invest in energy efficiency measures, net energy payments by New England residents are projected to actually decline.[2] Finally, recent work has suggested that a national Renewable Portfolio Standard requiring 15% renewables by 2020 would impact electricity prices within a likely range of -.2% to 2.1% when fully phased in.[3] Costs of an RPS in the Pacific Northwest are likely to be towards the low end, given our relatively favorable wind resources.[4]

To recap: insurance principles suggest that if a market existed for "global warming insurance", the private sector in Oregon would be willing to pay on the order of half a million to 3 billion dollars to avoid the risk of catastrophic outcomes. The risk, unfortunately, cannot be entirely avoided, but it can be mitigated. The three major current policy proposals that would help mitigate risk are likely to cost less than the low end estimate of willingness to pay for insurance, and in the case of clean cars, much, much less. Ignoring the non-catastrophic costs of global warming—loss of snowpack, gradual sea level rise, increases in agricultural pests and diseases-- and looking at insurance against catastrophic outcomes alone, these kinds of economically reasonable measures to reduce global warming gasses will be sound investments for Oregon.

6. Conclusion

This paper has outlined four potential scenarios with catastrophic consequences for Oregon's economy that could be triggered by global warming. A detailed

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[1] Adoption of California's clean car technology standards are likely to yield net benefits for Oregon consumers. Analyses for Washington state by the Department of Community, Trade and Economic Development (2004) estimate that in 2012 a new clean car will cost Washingtonians an additional $324 but will save more than $2000 in fuel costs. Additional financing costs for an average 2012 model car would be $7 month; fuel savings would be $11 month. On the whole, Washington is estimated to gain $2 billion in net savings by the year 2020. This finding is consistent with a recent study on fuel economy possibilities for vehicles by the National Academy of Sciences (2002), which concluded that, using known technologies, fuel economy could be raised substantially over the next decade at no net cost to consumers. SUV mileage, for example, could be improved by 25 to 40%, with the increase vehicle costs more than being offset by the (discounted) fuel savings. Moreover, the Academy agreed that these improvements could be achieved with no compromise in safety or performance.

[2] RGGI (2005: Page 4)

[3] Palmer and Burtraw (2006: Table 5). The authors present two extreme cases, in which co-firing is eliminated from the mix, and there is no learning for biomass IGCC technologies—these lead to cost increases of 4 and 3.8% respectively.

examination of one scenario—continental ice sheet collapse—reveals very high potential costs to the state. Utilizing estimates developed by Nordhaus and Boyer (2000), standard insurance theory suggests a willingness-to-pay to avoid economic risks of this type in Oregon of between $570 million and $3.24 billion dollars. Unfortunately, the insurance mechanism available—mitigation of greenhouse gasses—does not reduce financial risk with the same kind of certainty as a standard fire or auto insurance policy would. Nevertheless, given the high stakes, economically reasonable policies that reduce global warming emissions are likely to be sound investments. Based on available estimates of costs (and benefits) to Oregon, Clean Car standards, a utility cap-and-trade, and a utility RPS all qualify as such policies.

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